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Electromagnetic Pulse Propagation Modeling and Measurements of a Termination Cabinet

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***Abstract*—This work developed a methodology for transmission line modeling of cable installations to predict the propagation of conducted high altitude electromagnetic pulses in a substation or generating plant. The methodology was applied to a termination cabinet example that was modeled with SPICE transmission line elements with information from electromagnetic field modeling and with validation using experimental data. The experimental results showed reasonable agreement to the modeled propagating pulse and can be applied to other installation structures in the future.**

I. INTRODUCTION

High-altitude electromagnetic pulse (HEMP) events are a result of nuclear weapon detonations in the upper atmosphere and are a critical national infrastructure concern due to their broad geographic coverage and transient fields [1], [2]. A key area of HEMP vulnerability assessments for the electric grid involves testing sensitive equipment against conducted pulses that would couple onto power and signal lines. However, this testing is usually done directly at the component inputs, whereas coupling calculations and grid modeling occur at the system level. Previous experimental work using subsystem configurations in [3], [4], has shown that cables passing through elements like termination cabinets and breaker boxes can reflect significant amounts of the conducted HEMP environment, but these extensive tests are resource intensive. This work developed a model for transmission line modeling of circuit installations to address this gap between component-level testing and system-level assessments.

II. METHODOLOGY

The modeling methodology was demonstrated on a termination cabinet using transmission line elements approximating a wire over ground configuration with changes in discretization where ground distance could not be easily assumed. Electromagnetic (EM) field modeling with HFSS was used to determine the effects of individual ground structures within the cabinet on the effective cable impedance and the resulting pulse propagation. Specific elements modeled with EM included the aperture where the wire entered the cabinet, the terminal block crossing, and the metal support loops used to guide the wire vertically. These results were implemented into transmission lines of the cabinet that examined differences in wire pathing and ground distance inside and outside the cabinet.

Experimental pulse propagation data was obtained using the pulser described in [3] and [4]. The pulse traversing the system was measured by three current viewing transformers (CVTs) placed near the pulser (#1), before the cabinet (#2), and after the cabinet (#3), and the line was terminated in a 100 MΩ high voltage probe. Physical configurations of the ground structure were manipulated in a similar way to the models.

III. RESULTS AND CONCLUSIONS

An example of the measurement data compared to SPICE predictions of pulse propagation through the cabinet are shown in Fig. 1. This compares output cables 4 in. from ground (high Z_0) and near flat on the ground (low Z_0). In both cases the CVT #3 data at the cabinet output, corresponding to the HEMP signal that passes to the next component, agrees with some delay in the measurements due to slightly longer wiring in the cabinet than the model. Some variability in the impedance of the output cable increases the divergence upon reflection from the back of the setup. Comparisons across several cases showed good alignment and defined critical feature sizes in the EM models that were vital or could be ignored for HEMP propagation. This approach will be leveraged for other circuit elements in the future.

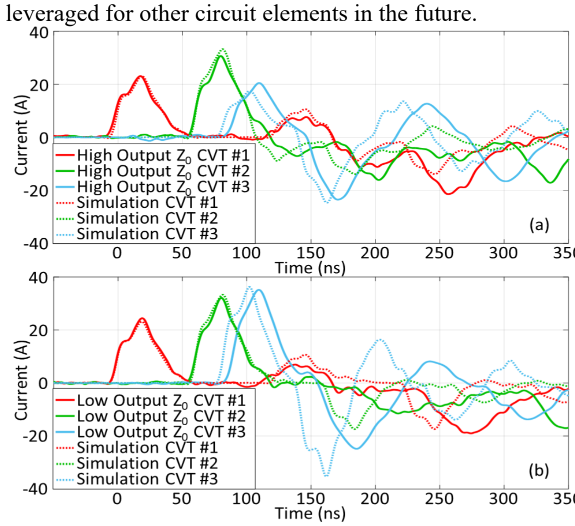

Figure 1. Comparison of measured and modeled results for (a) a high output Z_0 (~307 Ω) and (b) a low output Z_0 (~95 Ω).

Take-Home Messages:

- The objective of this work was to develop a modeling approach for circuit installations to predict HEMP propagation.
- Addresses key gap between system models and component tests.
- Enables correlation of historical test results to grid impact simulations without the need for expensive large-scale tests.

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